TRANSPORTATION ENGINEERING II

Contents

- Introduction and Scope of Traffic Engineering
- Traffic Studies
- Road Intersection and Traffic Control Devices
- Road Lighting
- Road Pavement
- Road Construction Technology
- Highway Maintenance, Repair and Rehabilitation
- Introduction to Bridge and Tunnel Engineering

Abhash Acharya

1

1

TRANSPORTATION ENGINEERING II

1.0 Introduction and Scope of Traffic Engineering

1.1 Definition of Traffic Engineering
1.2 Scope of Traffic Engineering
1.3 Traffic Characteristics
    1.3.1 Driver Characteristics
    1.3.2 Pedestrian Characteristics
    1.3.3 Vehicle Characteristics

Abhash Acharya

2

2

DEFINITION

- Deals with traffic studies, analysis and engineering application for the improvement of traffic performance on road.
- Institute of Traffic Engineers (USA) defines 'Traffic engineering is that phase of engineering which deals with the planning and geometric design of streets, highways, abutting lands and with, traffic operation thereon, as their use is related to the safe, convenient and economic transportation of persona and goods.'

Basic objectives is to achieve efficient, free and rapid flow of traffic with least number of traffic crashes.

Abhash Acharya

3

3

NECESSITY

- Concept of traffic engineering evolved with the development of motor vehicle.
- Traffic congestion, parking problem, environmental degradation, traffic crashes has created the attention to the performance characteristics of highway transportation.
    - Study and development for better geometric design, capacity, intersections, traffic regulations, signals, signs, roadway marking, terminals, street lighting, etc.

Abhash Acharya

4

4

SCOPE OF TRAFFIC ENGINEERING

• Traffic characteristics	Vehicular and road user
• Traffic study and analysis	Volume, Speed, Origin and Destination, Traffic flow characteristics, Parking, Traffic capacity, Crash study
• Traffic operation	Control (Signs, signals and markings), Regulations
• Designs	Intersection (Level and grade separated), Parking (On-street and off-street), Terminals, Lighting
• Traffic Planning	Mass transit facilities, Traffic management through policies, prioritization of public transportation
• Traffic Administration and Management	3E (Engineering, Enforcement and Education) 2E (Encouragement and Emergency Care) for road safety
• Researchc	

Abhash Acharya

5

5

HUMAN-VEHICLE-ENVIRONMENT SYSTEM

- Highway as an element of the total environment.
- Primary concern at the beginning was the ability to move people and goods rapidly and efficiently and little regards was given to the side effects of transportation on the environment or to depletion of natural resources.
    - Society demands a broader consideration of transportation impact, besides of efficiency judging to value and impact of transportation improvements, safety, ,aesthetic and effect on the social and physical environment.

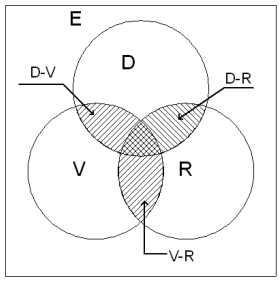


Figure: Vehicle, Road, Driver and Environment System

Abhash Acharya

6

6

HUMAN-VEHICLE-ENVIRONMENT SYSTEM

- Three recognized main elements of highway modes, i.e. human, vehicle and environment are to be considered for proper function of the system.
  - Driver need to have proper and adequate training and knowledge of highway mode before they drive any vehicles.
  - Human vehicle environment interactions develop driving skill creating safer driving resulting in reducing crashes.
  - The law and their enforcement provide guidance and motivation for safer and efficient driver behavior.

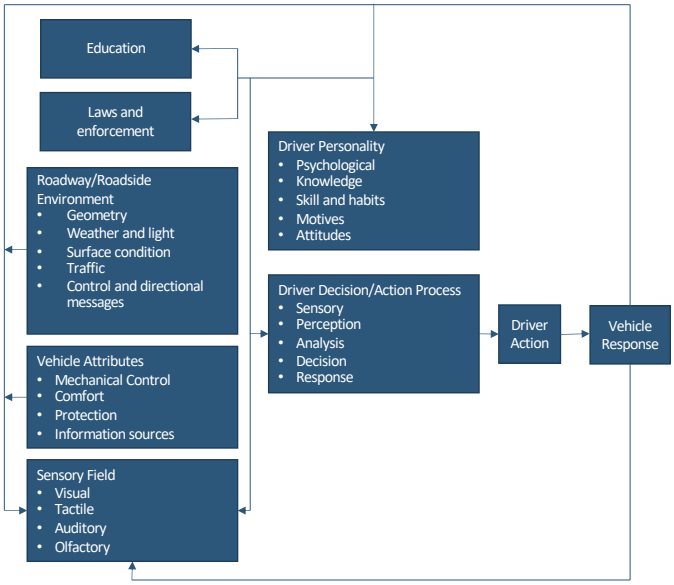


Figure: Human-Vehicle-Environment Operating System (FHWA, 1980)

Abhash Acharya

7

7

TRAFFIC CHARACTERISTICS

- Road User Characteristics

  Factors that affect road user characteristics are:
  - Physical Characteristics
  - Mental Characteristics
  - Psychological Characteristics
  - Environmental Factors
- Vehicular Characteristics
  - Static Characteristics
  - Vehicle Kinematics
  - Dynamic Characteristics

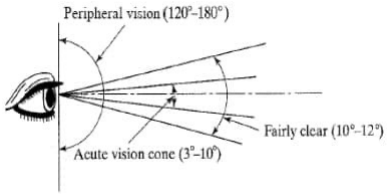
Abhash Acharya

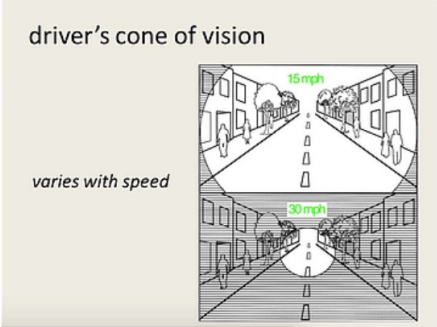
8

8

ROAD USER CHARACTERISTICS

- Physical Characteristics
  - Permanent: Vision, hearing, strength
  - Temporary: Fatigue, illness, effect of drugs
- Vision
  - About 90% of the information is received in visual.
  - Human eye sees and evaluates the size, shape and color of an object and estimate the distance and speed of the bodies.
  - Visual acuity is the ability to see fine details clearly.
  - Peripheral vision relates to an individual's ability to see objects not necessarily clearly. Such vision serves as a warning sign.





Abhash Acharya

9

9

ROAD USER CHARACTERISTICS

- Physical Characteristics
  - Permanent: Vision, hearing, strength
  - Temporary: Fatigue, illness, effect of drugs
- Hearing
  - Important to both drivers and pedestrians. However, more important for pedestrians.
  - Can be helpful in gaining information regarding warning sounds as sirens, horns, bells, etc.
  - It has been found that drivers with hearing problem can have 1.8 times more crashes than the drivers with normal hearing.
- Strength
  - Most important for drivers driving heavy vehicles.

Abhash Acharya

10

10

ROAD USER CHARACTERISTICS

- Physical Characteristics
  - Permanent: Vision, hearing, strength
  - Temporary: Fatigue, illness, effect of drugs
- Fatigue
  - Tired drivers usually suffer from lack of concentration and have longer perception-reaction time.
  - More likely to commit an error of judgement on the roadway.
- Illness
  - May cause physical inability to drive, mental tension and lack of concentration.

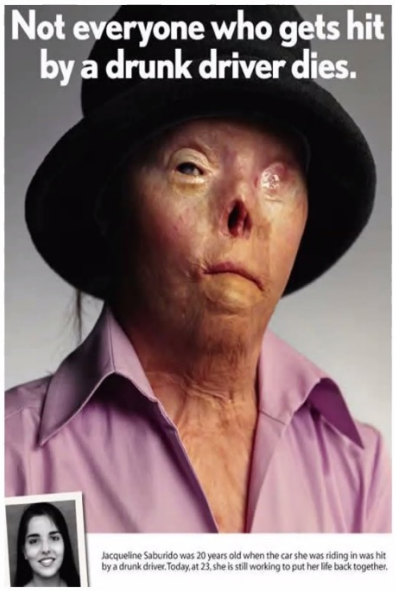
Abhash Acharya

11

11

ROAD USER CHARACTERISTICS

- Physical Characteristics
  - Permanent: Vision, hearing, strength
  - Temporary: Fatigue, illness, effect of drugs
- Effect of drug and alcoholic drink
  - Lack of concentration and overconfidence.



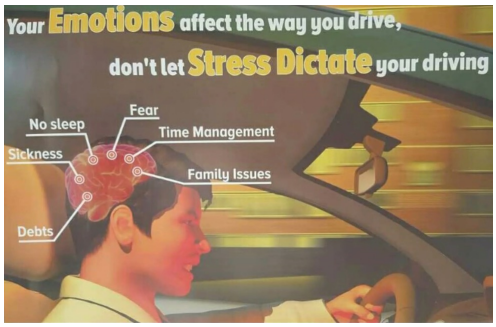
Abhash Acharya

12

12

ROAD USER CHARACTERISTICS

- Mental Characteristics
  - Knowledge, intelligence, skill, experience and literacy can affect the road user characteristics.
- Psychological Characteristics
  - Emotional factors as attentiveness, fear, anger, impatience, distraction and worries may lead to lack of concentration of road user towards traffic regulations and may not have right attitude to the other traffic.




Abhash Acharya

13

13

ROAD USER CHARACTERISTICS

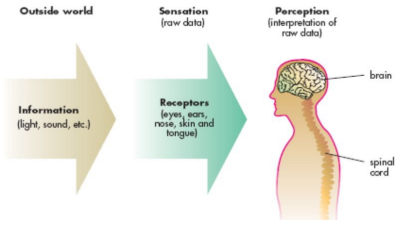
- Environmental Factors
  - Behavior of the road users are affected by various environmental conditions as traffic characteristics, traffic flow condition, atmospheric condition, locality of driving and facilities to the traffic, etc.


Abhash Acharya

14

14

PERCEPTION AND REACTION



- Perception is a process of extracting information from the environment.

The driver tends to attain movement from one point to other through three tasks.

- Control – physical manipulation of the vehicle through lateral and longitudinal control by steering, acceleration and braking.
- Guidance – driver's decision process, a task of selecting safe speed, path. Information comes from the environment, traffic control devices and other traffic surroundings.
- Navigation - driver's ability to execute a trip from origin to destination for which the information comes from maps, signs and landmarks.

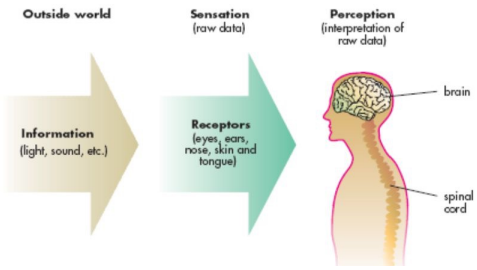
Abhash Acharya

15

15

PERCEPTION AND REACTION

- Perception time may be divided into two parts:
  - Perception delay – time between visibility and point of perception.
  - Appreciation interval – time required to determine that there is a potential hazard.
- Reaction involves analytical and decision making portion.
- Total reaction time involves reaction plus actual control response.



Abhash Acharya

16

16

DRIVING STRATEGY

Driver Strategy (Vanstrum and Caples, 1971)

- Distance 1 - during the perception time.
- Distance 2 - during the time needed to take a decision.
- Distance 3 - during the reaction time.
- Distance 4 - minimum stopping distance.
- T – True point of no return (last point at which action can be taken to avoid hazard).
  - If hazard is in motion, T will also be in motion.
- M – Mental point of driver (last point at which action must be taken).

Abhash Acharya

17

17

PIEV THEORY

- Perception – the recognition or realization of stimulus exists and requires response.
  - Sees a sign
- Intellection – an interpretation/identification of the stimulus.
  - Identifies it as a STOP sign
- Emotion – the determination of an appropriate response to the stimulus
  - Person is aware that, a brake need to be applied.
- Volition – the physical response resulting from the decision
  - Applies brake.

Abhash Acharya

18

18

VEHICULAR CHARACTERISTICS

- Static Characteristics
- Vehicle Kinematics
- Dynamic Characteristics

S.N.	Vehicle Type	Equivalency Factor
1	Bicycle, Motorcycle	0.5
2	Car, Auto Rickshaw, SUV, Light Van and Pickup	1.0
3	Light (Mini) Truck, Tractor, Rickshaw	1.5
4	Truck, Bus, Minibus, Tractor with Trailer	3.0
5	Non- Motorized Carts	6.0

(Source: NRS 2070)

Static	Doesn't change.
Kinetics	The study of forces that cause motion (eg. torque, gravity, friction, etc.)
Kinematics	The study of describing movement (eg. displacement, time, velocity, etc.) without taking into account forces that cause it.
Dynamics	Study of motions that result from forces.

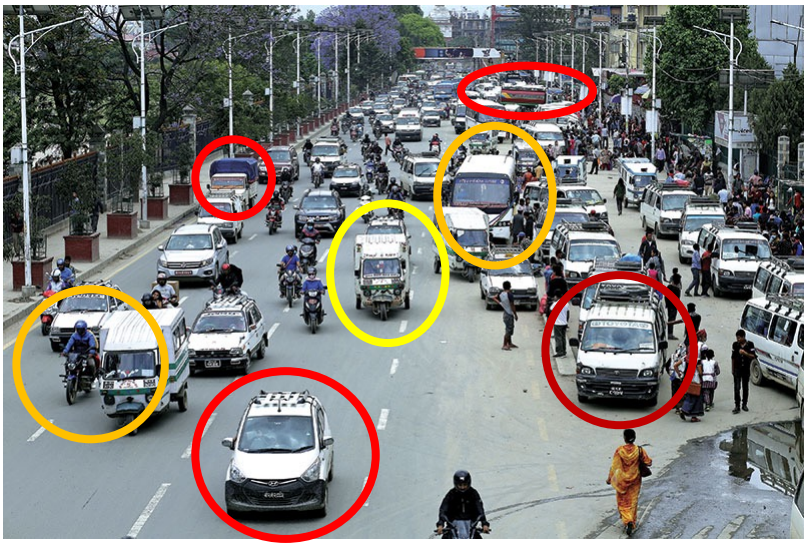
Abhash Acharya

19

19

VEHICULAR CHARACTERISTICS

- Static Characteristics
  - Height of the vehicle
  - Height of the driver seat
  - Height of the headlight
  - Clearance below chassis
  - Length of the vehicle
  - Width of the vehicle
  - Length of the wheelbase
  - Gross weight



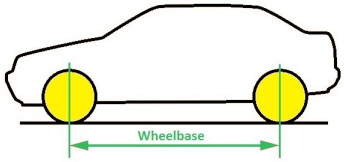
Abhash Acharya

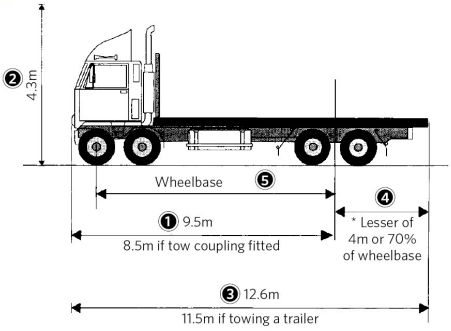
20

20

VEHICULAR CHARACTERISTICS

- Static Characteristics
  - Height of the vehicle
  - Height of the driver seat
  - Height of the headlight
  - Clearance below chassis
  - Length of the vehicle
  - Width of the vehicle
  - Length of the wheelbase
  - Gross weight



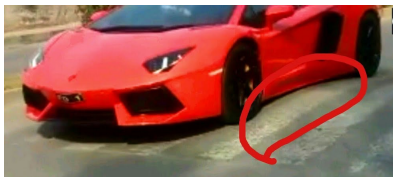


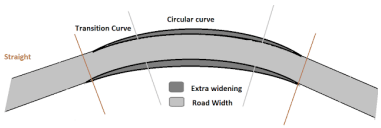
Heavy rigid motor vehicle dimensions

Abhash Acharya

VEHICULAR CHARACTERISTICS

- Static Characteristics
  - Height of the vehicle – affects the clearance needed under structure and center of gravity.
  - Height of the driver seat – affects the visibility distance.
  - Height of the headlight – affects sight distance at valley curve for night driving.
  - Clearance below chassis – limits driveway vertical profile, humps and dips.
  - Length of the vehicle – affects capacity, maneuverability, turning radius, overtaking distances.
  - Width of the vehicle – affects traffic lane, shoulder, traffic facilities.
  - Length of the wheelbase – affects turning radius, extra-widening.
  - Gross weight – affects the structural design of pavements and cross drainage structures.





Maximum Width, m	2.50
Maximum Height, m	4.75
Maximum Length, m	18.00
Maximum single axle load, kN	100

(Source: NRS 2070)

Abhash Acharya

VEHICULAR CHARACTERISTICS

- Static Characteristics

From the consideration of providing sight distance equal to stopping distance the height of driver's eye and the object are taken as 1.2m and 0.15m above pavement surface respectively.

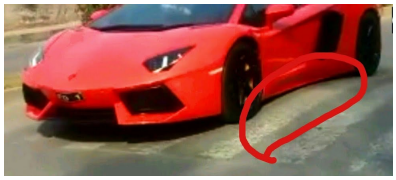
(Source: NRS 2070)

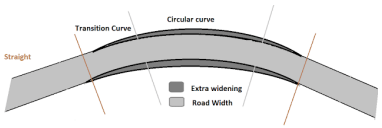
From the consideration of providing sight distance equal to the overtaking distance or twice the stopping distance for single lane road (whichever is higher) with the height of driver's eye 1.2 m above pavement surface.

(Source: NRS 2070)

Minimum length of valley curve (L) from the consideration of night visibility of road surface by the illumination by the head light is to be found as follows(taking 0.75m as height of mounting of head light above pavement surface, and 2° as the angle of illumination of the headlight):

(Source: NRS 2070)





Maximum Width, m	2.50
Maximum Height, m	4.75
Maximum Length, m	18.00
Maximum single axle load, kN	100

(Source: NRS 2070)


Abhash Acharya

23

23

VEHICULAR CHARACTERISTICS

- Dynamic Characteristics
  - Dynamic characteristics of vehicle affecting road design are speed, acceleration and braking characteristics.
  - Speed of the vehicle – affects sight distance, super elevation, length of transition curve, limiting radius on horizontal curve, width of pavement, capacity of traffic lane, and design and control measures on intersection.
  - Power of the vehicle – Power of the heaviest vehicle and its gross weight governs the permissible and limiting values of gradient on roads.
  - Braking characteristics – The deceleration and braking characteristics of vehicle depend on the design and type of braking system and its efficiency.


Abhash Acharya

24

24

VEHICULAR CHARACTERISTICS

- Braking Test
  - For braking test out of the following three parameters at least two are needed.
    - Initial speed of vehicle (u) in m/s.
    - Braking distance i.e. distance travelled from the instant the brakes are applied to the instant vehicle stops (L) in meters.
    - Duration i.e. time 't' in second, in bringing vehicle to dead stop.

  Using these parameters the average skid resistance of the pavement is calculated.

  Force = ma

  F = Frictional force developed = f*W

  where, W is the weight of the vehicle and f is the average skid resistance.

  f W = (W*a)/g

  f = a/g

Abhash Acharya

25

25

NUMERICAL

f = a/g

- A vehicle traveling at 55 kmph was stopped within 2.5 seconds after the application of brakes. Calculate the average skid resistance.

u = 55kmph

u = $55*\frac{5}{18}$ = 15.277 m/secs

v = 0 m/secs

t = 2.5 seconds

We have,

v = u – at

a = 15.277 / 2.50

a = 6.11 m/s^2

f = a/g

f = 6.11 / 9.81

f = 0.622

Abhash Acharya

26

26

NUMERICAL

f = a/g

- A vehicle moving at 50 kmph speed was stopped by applying the brake and the length of skid mark was 15 m. If the average skid resistance of the pavement is 0.85, find the brake efficiency of the test vehicle.

u = 50 kmph

$u = 50 * \frac{5}{18} = 13.89$ m/secs

S = 15 m

f = 0.85

Calculation of average skid resistance developed

f = a/g

Calculation of a

$v^2 = u^2 - 2as$

$0 = 13.89^2 - 2*a*15$

a = 6.43

f' = a/g

f'= 6.43/9.81

f' = 0.655

$\text{Brake efficiency} = \frac{\text{Average skid resistance developed}}{\text{Average skid resistance of pavement}} * 100$

$\text{Brake efficiency} = \frac{0.655}{0.85} * 100$

Brake efficiency = 77.60 %

Alternative Approach:

$S = \frac{V^2}{254*f*\eta}$

$15 = \frac{2500}{254*0.85*\eta}$

$\eta = 77.11\%$

Abhash Acharya

27

27

NUMERICAL

f = a/g

- A vehicle was stopped in 1.8 s and the skid marks measured was 7.5m. Determine the average skid resistance.

t = 1.8 s

S = 7.5 m

Calculation of 'a'

v = u – at

u = at …….. a)

$v^2 = u^2 - 2aS$

$a^2t^2 = 2*a*7.50$ (From a)

$a*1.8^2 = 15$

$a = 4.63$ m/s^2

f = a/g

f = 4.63/9.81

f = 0.472

Abhash Acharya

28

28

NUMERICAL

- A vehicle has a wheel base of 6.1 m. What is the value of off tracking while negotiating a curved path with a mean radius of 35 m.

Length of wheel base (l) = 6.1 m

Radius (R) = 35 m

Off tracking = $\frac{l^2}{2R}$

Off tracking = $\frac{6.1^2}{2*35}$

Off tracking = 0.531 m

Abhash Acharya

29

NUMERICAL

$S = \frac{v_1^2 - v_2^2}{2g(f \pm i)\eta}$

$S = \frac{v_1^2 - v_2^2}{254(f \pm i)\eta}$

- A driver of a car applied brakes and avoided hitting the parked vehicle on the roadway. The car left the skid marks of 37m. Assuming f = 0.62 and braking efficiency of 90%, determine whether the driver was violating the 50 kmph speed limit at that location if the driver was travelling
  - Uphill on 3.5° slope
  - Downhill on 2.45° slope
  - On the level roadway

Case I - $v_1 = \sqrt{254 * 37 * (0.62 + Tan\ 3.5) * 0.90}$ = 75.90 kmph > 50 kmph

Case II - $v_1 = \sqrt{254 * 37 * (0.62 - Tan\ 2.45) * 0.90}$ = 69.87 kmph > 50 kmph

Case III – $v_1 = \sqrt{254 * 37 * 0.62 * 0.90}$ = 72.42 kmph > 50 kmph

Abhash Acharya

30

NUMERICAL

$S = \frac{v_1^2 - v_2^2}{2g(f \pm i)\eta}$ $S = \frac{v_1^2 - v_2^2}{254(f \pm i)\eta}$

- The driver of a vehicle traveling at 80 kmph up a grade required 9 m less to stop after he applies the brake than the driver traveling at the same initial speed down the same grade. If the coefficient of friction between tire and the pavement is 0.5, what is the percent grade and what is the braking distance down the grade?

$\frac{V^2}{254(f+i)} = \frac{V^2}{254(f-i)} - 9$

$\frac{V^2}{254}\left[\frac{1}{f+i} - \frac{1}{f-i}\right] = -9$

On Solving, i = 0.044

Calculation of braking distance down the grade

$S = \frac{V^2}{254(f-i)\eta}$

$S = \frac{80^2}{254\,(0.50 - 0.044)}$

S = 55.30 m

Abhash Acharya

31

31

NUMERICAL

- A truck traveling at 45 kmph is approaching to a stop sign. At time t_0 and a distance of 20m, the truck begins to slow down by decelerating at 5 m/s^2. Will the truck be able to stop in time?

u = 45 kmph

u = 45 * 5/18 = 12.5 m/secs

a = -5 m/s^2

$v^2 - u^2 = 2aS$

$-12.5^2 = 2*(-5)*S$

S = 15.625 < 20 m

The truck will be able to stop in time.

Abhash Acharya

32

32

VEHICULAR CHARACTERISTICS

- Vehicle Kinematics
  - The fundamental relationship between force and acceleration is given by:
    - F = ma

i. For the uniform acceleration

- speed-acceleration function:

$$\frac{dv}{dt} = a$$

$$or,\ dv = adt$$

$$\int_{v_0}^{v} dv = at$$

$$v - v_0 = at$$

$$or,\ v = v_0 + at \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Abhash Acharya

33

33

VEHICULAR CHARACTERISTICS

- For distance-time function

$$\frac{dx}{dt} = v \Rightarrow dx = (v_0 + at)dt$$

$$x = v_0 t + \tfrac{1}{2} a t^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

- For distance-speed function;

$$x = \frac{v^2 - v_0^{\,2}}{2a} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

- Where, a = acceleration; v = speed; v_0 = initial speed; x = distance; t = time

Abhash Acharya

34

34

VEHICULAR CHARACTERISTICS

ii. Non-uniform acceleration

- special case-acceleration varies inversely to speed

$$\frac{dv}{dt} = \alpha - \beta v$$

α,β=constants

α=maximum acceleration attainable

- Equation for distance as a function of time

$$x = \frac{\alpha t}{\beta} - \frac{\alpha}{\beta^2}(1 - e^{-\beta t}) + \frac{v_0}{\beta}(1 - e^{-\beta t})$$

- Velocity time relationship $v = \frac{\alpha}{\beta}(1 - e^{-\beta t}) + v_0 e^{-\beta t}$

- Acceleration time relationship $\frac{dv}{dt} = (\alpha - \beta v_0)e^{-\beta t}$

Abhash Acharya

For speed to be maximum $\frac{dv}{dt} = 0 \Rightarrow \alpha - \beta v = 0$

Hence, $v = \frac{\alpha}{\beta} = v_{max}$

Integrating the above equation (1) between v and v_0, we get

$$\int_{v_0}^{v} \frac{dv}{\alpha - \beta v} = \int_0^t dt$$

$$-\frac{1}{\beta}\log(\alpha - \beta v)\Big|_{v_0}^{v} = t$$

$$\frac{\alpha - \beta v}{\alpha - \beta v_0} = e^{-\beta t}$$

$$v = \frac{\alpha}{\beta}(1 - e^{-\beta t}) + v_0 e^{-\beta t} \quad \ldots\ldots\ldots\ldots\ldots(1)$$

This gives the relation between speed and time.

The equation for distance as a function of time is

$$\frac{dx}{dt} = v \Rightarrow \frac{dx}{v} = dt \Rightarrow dx = v.dt$$

Integrating the equation $\int_0^x dx = \int_0^t \left\{\frac{\alpha}{b}(1 - e^{-\beta t}) + v_o e^{-\beta t}\right\} dt$

$$x = \frac{\alpha t}{\beta} - \frac{\alpha}{\beta^2}(1 - e^{-\beta t}) + \frac{v_0}{\beta}(1 - e^{-\beta t}) \quad \ldots\ldots\ldots\ldots(2)$$

Similarly, the acceleration - time relationship can be obtained as:

$$a = \frac{dv}{dt} = \alpha - \beta v$$

Putting the value of equation (1)

$$a = \alpha - \beta\left\{\frac{\alpha}{\beta}(1 - e^{-\beta t}) + v_0 e^{-\beta t}\right\}$$

$$a = \frac{dv}{dt} = (\alpha - \beta v_0)e^{-\beta t}$$

35

35

NUMERICAL

- A driver traveling at 50 kmph behind another car decides to pass it and accelerate it. If the rate of acceleration 'a' is given by the relation $\frac{dv}{dt}$ = 1.2 – 0.015v where v is the speed in m/s and t is the time in seconds, find
  - a) The rate of acceleration after 8 seconds.
  - b) Time taken to attain a speed of 100 kmph.
  - c) Distance travelled by the car in 160 seconds.

$\frac{dv}{dt}$ = 0.89 m/s²

t = 15.80 seconds

x = 8.793 km

ii. Non-uniform acceleration

- special case-acceleration varies inversely to speed

$\frac{dv}{dt} = \alpha - \beta v$ α,β=constants α=maximum acceleration attainable

- Equation for distance as a function of time

$x = \frac{\alpha t}{\beta} - \frac{\alpha}{\beta^2}(1 - e^{-\beta t}) + \frac{v_0}{\beta}(1 - e^{-\beta t})$

- Velocity time relationship $v = \frac{\alpha}{\beta}(1 - e^{-\beta t}) + v_0 e^{-\beta t}$

- Acceleration time relationship $\frac{dv}{dt} = (\alpha - \beta v_0)e^{-\beta t}$

Abhash Acharya

36

36

TIRE FRICTION

- Skid
  - It occurs when the distance travelled along the road surface is greater than circumferential movement of tires. It happens when wheel slides without revolving.
- Slip
  - It occurs when the driving wheels of a vehicle revolve more than the longitudinal movement. This occurs on a slippery and wet road surfaces.

  The tire slip is calculated using the formula:

$$S_T = \frac{V_u - V_t}{V_u} * 100\%$$

Where, S_T = Tire slip

V_u = Velocity of vehicle

V_t = Circumferential velocity

Abhash Acharya

37

37

SKID RESISTANCE

- Retarding force generated due to the interaction between the pavement and locked tire when the vehicle is moving.
- Maximum deceleration depends upon the coefficient of friction between the tire and the pavement.

Factors affecting skid resistance

- Aggregate quality – Aggregate polish reduces the skid resistance.
- Binder – Soft or temperature susceptible binders may cause bleeding reducing skid resistance.
- Climate – In hot climate, bitumen may soften and the chances of bleeding increases, reducing skid resistance.
- Surface drainage – Poor surface drainage leads to accumulation of water on surface and causes loss of skid resistance.

The distance travelled while skidding from a speed v_1 to v_2 on a slope of γ is

$$S = \frac{v_1^2 - v_2^2}{2g\cos\gamma(f \pm \tan\gamma)}$$

For level surface

$$S = \frac{v_1^2 - v_2^2}{2gf}$$

Abhash Acharya

38

38